Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 78 (2015) 327 – 333

Energy Procedia

6th International Building Physics Conference, IBPC 2015

The analysis of building façade sheltering by integrated energy simulation

Wei You[a], Wowo Ding[a,]*

[a]School of Architecture and Urban Planning, Nanjing University, Hankou road 22, Nanjing 210093, China

Abstract

This paper investigates the influence of the uneven façade design on energy consumption from a integrated perspective. The computer simulation techniques were adopted to assess the effects of the façade sheltering sizes on the total energy consumption. To facilitate the model establishment, some scripts are written by MATLAB. The simulation results indicate that the façade sheltering generally makes the energy consumption increase, regardless of the sheltering types. And the influence range of the sheltering on the total energy consumption relates closely to the sheltering condition and the façade window position.

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL

Keywords: Building façade sheltering; Integrated energy consumption; EnergyPlus; Daylighting; Natural ventilation;

1. Introduction

Due to the complexity of building design, building façade often has uneven changes. These changes not only inspire architects to create interesting external images of buildings, but also have great influences on room's natural lighting and ventilation, which relate closely to the electrical lighting and air-conditioning energy consumption. However, in the design process, how to decide the size of sheltering wall to effectively lead natural wind and(or) shelter excess solar heating is a challenge for architects. Therefore, we need to understand the relationships between façade sheltering shapes and the integrated energy consumption.

* Corresponding author. Tel.: +86-25-8359-3020; fax: +86-25-8359-5673.
E-mail address: dww@nju.edu.cn

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL
doi:10.1016/j.egypro.2015.11.655

Some previous studies had demonstrate the influence of building façade configurations on the daylighting, natural ventilation and associated energy consumption [1,2], and different window-to-wall ratio (WWR), room geometries and directions were analyzed. However, most of the research only discussed a simple rectangle building, without considering the uneven façade sheltering. The sheltering effects of building façade have also been evaluated in terms of daylighting and thermal performance. But most of the research focused on the shading devices performance [3,4], and few studies evaluated the relatively complex building forms with self-shading effects [5]. What's more, most of the analyses carried out on sheltering effects are only confined to either thermal or lighting aspect, which is limited for architects to make decision.

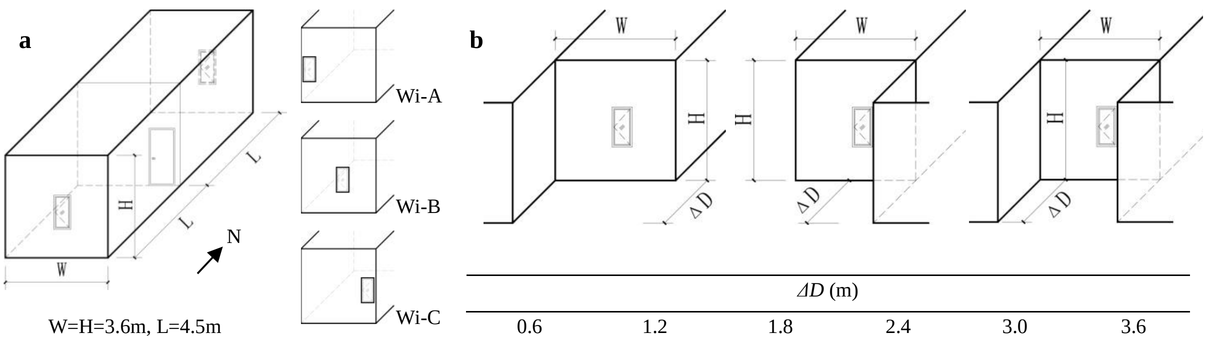
In this research, the influence of façade sheltering design on energy consumption is analyzed from an operable aspect, and three types of sheltering conditions with three façade configurations (window position changes) are discussed. The analytical method use in this paper is computer simulation technology. The simulation tool used was the EnergyPlus and Airpak. They are combined to simulate the annual energy consumption under daylighting and natural ventilation conditions. To facilitate the model establishment of EnergyPlus and Airpak, some scripts are developed by MATLAB to set up parameters and transfer data between the two software. With these programs, A prototypical room unit consisting of two zones is defined and a series EnergyPlus energy simulation are performed for different sizes of the façade sheltering schemes. Then the relationships of the total energy demand and the sizes of the façade shelterings are analyzed.

2. Research methods

2.1. Façade sheltering form

As the aim of this study is to obtain the principle that how the uneven changes of building façade influences the daylighting, natural ventilation and associated energy consumption, a generic rectangular room with a floor-plan of 3.6m × 9.0m is adopted to serves as the base case, which considers unsheltered condition, as show in Fig. 1(a). The room's long axis is aligned south-north direction and one internal wall is added in the middle of the room to separate the calculation room into a south-faced room and a north-faced room. This model is able to reflect the sun-lighting of south and north direction rooms and airflow features of multi-zones. These sizes fully consider the requirements in structure and function, such as office, apartment, etc.

Façade sheltering conditions are considered for the south-faced room. With regard to the types of façade uneven changes, the sheltering conditions are divided into three types: east-side sheltering (E-Shade), west-side sheltering (W-Shade)and two-sides sheltering (D-Shade), as show in Fig. 1(b). The sheltering sizes (ΔD) of façade shelters are set as six dimensions - from 0.6m to 3.6m at 0.6m increments. The south and north façade each has a rectangular window with the window size of 0.6m × 1.2m. The window can be fully opened, and the windowsill is 0.9m. Three horizontal locations representing left (Wi-A), middle (Wi-B) and right window (Wi-C) are considered in the south room, which reflects the sheltering effects. The façade Wi-B is adopted as the north façade of the north room.



Base case W-Shade E-Shade D-Shade

Fig. 1. (a) Calculated room and façade window configuration; (b) Façade sheltering types and changing.

2.2. Building specifications and data processing

The façade configurations are investigated for an air-conditioned office room, located in Nanjing (China), which belongs to the hot summer and cold winter zone according to China climate classification. The building envelope construction are set according to the common-used building construction in engineering practice at present, as show in table1. And the window is double-layer hollow glass window (6mm glass +12mm air+6mm glass), with the direct solar energy transmission coefficient of 0.53. The internal gains of people, equipment and lighting are set according to the Chinese National Standards '*Public Building Energy-Saving Design Standards*', with 11 W/m^2, 4 W/m^2 and 20 W/m^2 respectively [6].

Table 1. Thermo-physical properties of building materials (TH: Thickness, TC: thermal conductivity, DE: density, SH: specific heat).

Building envelope	Major material	TH (mm)	TC (W m^{-1} k^{-1})	DE (Kg m^{-3})	SH (J Kg^{-1} K^{-1})
Roof	Forming ceramic insulation board	120	0.08	280	1000
	Coiled material coating waterproof	3	0.170	600	2842
	Reinforced concrete	120	1.74	2500	2500
External wall	Coating	2	0.93	1700	1911.5
	Thermal-insulating blocks	200	0.268	1200	560
	XR inorganic thermal mortar	10	0.052	184	1170
Ground	Cement mortar	20	0.93	1800	1050
	Foaming ceramic insulation board	35	0.08	280	1000
	Coiled material film waterproof	10	0.170	600	2842
	Reinforced concrete	100	1.74	2500	920

2.3. Integrated simulation model

The integrated simulation of daylighting and natural ventilation is performed by EnergyPlus, which is an dynamic energy simulation program. Its daylight module and natural ventilation module can be coupled with thermal module to calculate the daylight, airflow and associated energy consumption. The accuracy and validity have been evaluated by numerous experiment [7,8]. The tests revealed that the simulation results of EnergyPlus showed reasonable agreement with measurement data and is suitable for the building envelope design in the design stage.

For daylight simulation, the daylight/detailed module of EnergyPlus is used to calculate the interior daylight at each heat-balance time-step when the sun rises up. Two reference points for the daylight calculation are chosen in each room unit to consider the direct and diffuse light. The two points are placed on the central axis of the office, at 1.0 m apart from the inner and outer wall of the room, at a height of 0.80 m above the floor. To calculated the lighting energy saving from daylight, continuous dimming control mode is used to determine the supplementary lighting energy by calculating lighting electric reduction factor.

For natural ventilation, the multi-zone network module is adopted. Using this module, the windows are defined in the 'detailed opening' objects, which allow the detailed description of window configurations. Temperature dependent ventilation mode is selected to allow the window to be opened when the interior air temperature is higher than outside air temperature. Wind pressure coefficient (C_p) is a important boundary condition for natural ventilation. In EnergyPlus, the default C_p values are 'surface averaged', which can only be used to calculate rectangular building. So in this research, the 'input' mode is adopted, and Airpak, a computational fluid dynamics (CFD) software, is used to provide wind pressures at the window area, then the C_p values are calculated according to the following equation:

$$C_p = \frac{p_w - p_0}{0.5\rho U_h^2} \tag{1}$$

Where P_0 is the static reference pressure (Pa), ρ is the air density (kg/m^3) of the approach wind and U_h is the reference wind velocity (m/s) taken at the height *h* of the building. To provide valid wind pressure data of building façade, the establishment of the CFD model follows AIJ (Architectural Institute of Japan) guideline[9].

2.4. MATLAB based data process programs

The data process program, which is developed by MATLAB, is composed of three parts. The first part is the building forms and boundary condition data processing module, mainly responsible for the functions of building geometry and boundary condition data, including building database establishment, geometry and boundary condition data saving and reading. The second part is the simulation software parameters processing module, mainly responsible for the EnergyPlus and Airpak model establishment according to input file format, data (C_p values) transfer between the two softwares and calculation performing. In this research, 12-direction wind pressure coefficients (the wind direction interval is 30°) is provided for EnergyPlus and a bat file is generated to automatically perform the calculation. The third part is the simulation results processing module, which is divided into simulation results analyses and data visualization modules.

3. Result and analysis

3.1. Simulation result

Fig.2 shows the influence of façade sheltering size on the south room's total energy consumption (heating, cooling and lighting load, E_{tot}) under east-side, west-side and double-side sheltering conditions. As the sheltering size (ΔD) increases, the total energy consumption increases for all the three sheltering conditions. This changing rule is especially obvious when the façade window is located closer to the ease-side or west-side sheltering. For example, under the west-side sheltering condition (Fig.2a), as the sheltering sizes increases from 0.0m to 3.6m, the south room’s total energy consumption increases by 20.5%, 4.3% and 2.8%, corresponding to the windows located at the west-side (Wi-A), middle (Wi-B) and east-side (Wi-C) of the façade, respectively.

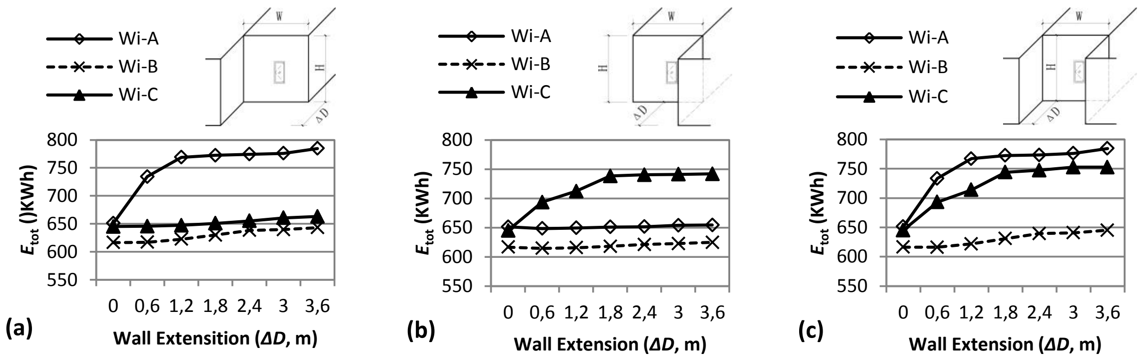


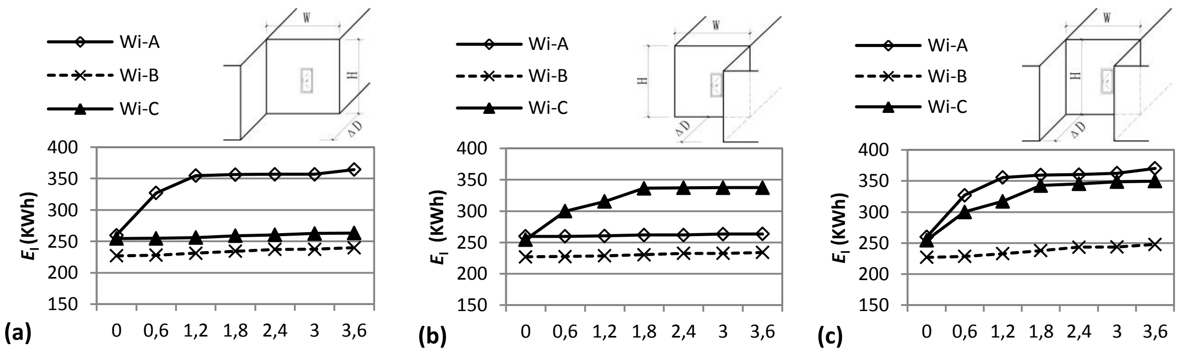
Fig. 2. Influence of façade sheltering size on the south room's total energy consumption (E_{tot}) under (a) West-side sheltering (W-Shade), (b) East-side sheltering (E-Shade), (c) Double-side sheltering (D-Shade).

The turning point of the sheltering size (ΔD) on the total energy consumption appears at about 1.2~1.8m, which relates to the sheltering conditions and façade window opening positions. It is mainly due to sheltering effects of the west-side or (and) east-side shelter(s) on the façade window. When the window is situated nearby the façade sheltering, the total energy consumption undergoes a quickly rise then a slowly rise with the sheltering size increasing. Under the west-side sheltering, as show in fig. 2a, when the façade window is located at the west-side (Wi-A), the turning point of the sheltering size is about 1.2m. While under the east-side sheltering, the turning point of the sheltering size appears at about 1.8m with the façade window locating at the east-side (Wi-C), as show in fig. 2b. Under the double-side sheltering condition (fig. 2c), the total energy increase under the duplicate effect of the west-side and east-side shelterings. However, the changing range is mainly affected by the façade window position and the nearest sheltering. When the window locates at the west-side (Wi-A) of the façade, the total energy consumption is more influenced by the west-side sheltering, and vice versa. When the window locates at the middle (Wi-B) of the façade, the west-side sheltering exerts relatively more effect, comparing with the east-side sheltering.

3.2. Result analysis

The simulation results indicate that the façade sheltering generally makes the energy consumption increase, regardless of the sheltering conditions types. It is mainly due to the integrated sheltering effects of the façade shelters on daylighting, solar heating and natural ventilation, which synthetically influence the lighting, heating and cooling energy consumption. Among these influence factors, daylighting exerts relatively more effect, as show in fig. 3(a-c). As the sheltering size increases, the lighting energy consumption (E_l) increases, due to the decrease of daylight. When the façade window is located closer to the sheltering, the lighting energy is more of effect to the size changing of the façade sheltering. The changing rule of the lighting energy consumption shows relatively good agreement to the total energy consumption.

As the sheltering size increases, the heating (E_h) or cooling (E_c) energy consumption also increases. But as for the east-side and west-side shelterings, the effects are different. Fig.3(d-f) show the influence of sheltering size on the heating energy consumption, under different sheltering conditions. Under the west-side sheltering, the heating load increases. However, under the east-side sheltering, the heating load nearly keeps still. It might be because of the sheltering effects on the solar heating gain from window. But as for the cooling energy consumption, the sheltering exerts inverse effects, as show in fig.4(d-f). It is mainly due to the prevalent southeast monsoon in Nanjing area in summer. The east-side shelter mainly blocks the wind, and the west-side shelter leads the wind. The leading and blocking effects of the façade sheltering to natural ventilation can be further confirmed by the calculation of the air flow rate per hour (ACH), as show in fig.4(a-c). In the west-side sheltering condition, the ACH value increases slightly, which reduce the cooling energy consumption a little in the summer. But in the east-side sheltering condition, ACH values decrease greatly, which increase the summer cooling energy consumption.



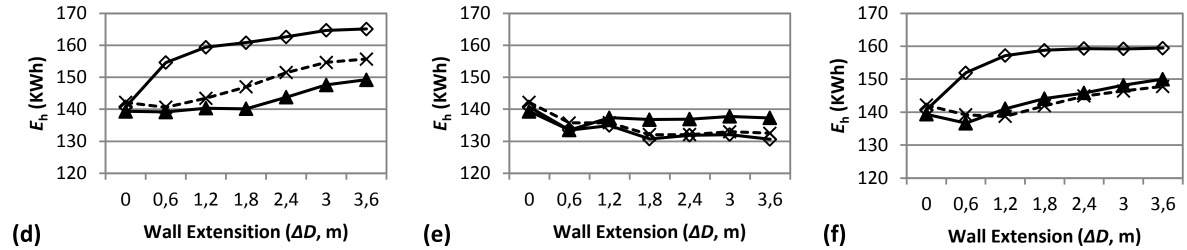


Fig. 3. Influence of façade sheltering size on the south room's lighting energy consumption (E_l) and heating energy consumption (E_h) under (a, d) West-side sheltering (W-Shade), (b, e) East-side sheltering (E-Shade), (c, f) Double-side sheltering (D-Shade).

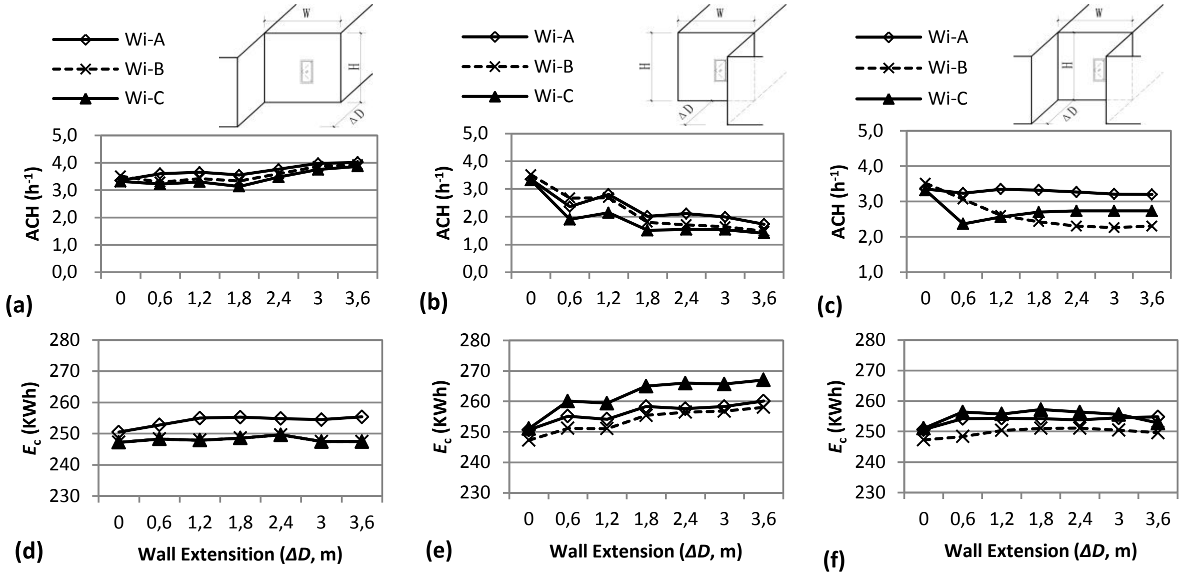


Fig. 4. Influence of façade sheltering size on the south room's air change rate per hour (ACH) and cooling energy consumption (E_c) under (a, d) West-side sheltering (W-Shade), (b, d) East-side sheltering (E-Shade), (c, f) Double-side sheltering (D-Shade).

4. Conclusion

This paper presents a method and a series of simulation process in evaluating the sheltering effects of uneven façade on the integrated energy consumption for office building in the hot summer and cold winter zone of China. The results show that as the sheltering size increases, the total energy consumption generally increases, regardless of the sheltering conditions types. The increase of the energy consumption is mainly due to daylighting. The turning point of the sheltering size on the total energy consumption can be found out, and the value relates closely to the sheltering conditions and the façade window positions.

Acknowledgements

This work is supported by the Specialized Research Fund for the Doctoral Program of Higher Education of China under Grant number: 20120091110055.

References

[1] Goia F, Haase M, Perino M. Optimizing the configuration of a façade module for office buildings by means of integrated thermal and lighting simulations in a total energy perspective. Appl Energy 2013; 108:515–527

[2] You W, Qin MH, Ding WW. Improving Building Façade Design Using Integrated Simulation of Daylighting, Thermal Performance and Natural Ventilation. Build Simul 2013;6(2):269-282.

[3] Alzoubi HH, Al-Zoubi AH. Assessment of building façade performance in terms of daylighting and the associated energy consumption in architectural spaces: Vertical and horizontal shading devices for southern exposure façades. Energy Convers Manage 2010; 51:1592–1599.

[4] Shen E, Hu J, Patel M. Energy and visual comfort analysis of lighting and daylight control strategies. Build Environ 2014: 78:155-170

[5] Guedi Capeluto I. Energy performance of the self-shading building envelope. Energy Build 2003; 35:327–336.

[6] Lang SW, Lin HY, Tu FX, et al. Design Standard of Energy Efficient Designing for Public Buildings. Bejing: China Architecture and Building Press; 2005. (in Chinese)

[7] Ramos G, Ghisi E. Analysis of daylight calculated using the EnergyPlus programme. Renew Sust Energy Rev 2010; 14(7):1948-1958.

[8] Zhai Z, Johnson MH, Krarti M. Assessment of natural and hybrid ventilation models in whole-building energy simulations. Energy Build 2011; 43(9):2251-2261.

[9] Tominaga, Y, Mochidab A, Yoshiec R, et al. AIJ Guidelines for Practical Applications of CFD to Pedestrian Wind Environment around Buildings. J Wind Eng Ind Aerodyn 2008; 96 (10-11): 1749-1761.